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BEHAVIOR OF RATS UNDER FIXED CONSECUTIVE NUMBER SCHEDULES: EFFECTS OF DRUGS OF ABUSE

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Four rats responded under a simple fixed consecutive number schedule in which eight or more consecutive responses on the run lever, followed by a single response on the reinforcement lever, produced the food reinforcer. Under this simple schedule, dose–response curves were determined for diazepam, morphine, pentobarbital, and phencyclidine. The rats were then trained to respond under a multiple fixed consecutive number schedule in which a discriminative stimulus signaled when the response requirement on the run lever had been completed in one of the two fixed consecutive number component schedules. Under control conditions, the percentage of reinforced runs under the multiple-schedule component with the discriminative stimulus added was much higher than the percentage of reinforced runs under the multiple-schedule component without the discriminative stimulus. All of the drugs decreased the percentage of reinforced runs under each of the fixed consecutive number schedules by increasing the conditional probability of short run lengths. This effect was most consistently produced by morphine. The drugs produced few differences in responding between the multiple fixed consecutive number components. Responding under the simple fixed consecutive number schedule, however, was affected at lower doses of the drugs than was responding under the same fixed consecutive number schedule when it was a component of the multiple schedule. This result may be due to the difference in schedule context or, perhaps, to the order of the experiments.

Key words: fixed consecutive number schedule, stimulus control, drug, multiple schedule, lever press, rats

In 1958, Mechner reported the use of what later became known as the fixed consecutive number (FCN) procedure (Mechner & Latranyi, 1963). To earn the reinforcer under this procedure, the subject must first emit a minimum number of consecutive responses on one lever (run lever) and then emit a single response on a second lever (reinforcement lever). If a subject switches from the run lever to the reinforcement lever prior to the completion of the minimum number of consecutive responses, the reinforcer is withheld and the run lever response requirement is reset.

The FCN procedure can be modified such that, when the subject emits the required consecutive number of responses on the run lever, a stimulus change occurs. By signaling that the run requirement has been met, this stimulus change sets the occasion for the response on the reinforcement lever. This modified FCN schedule is typically designated as the FCN-S^D schedule (Laties, 1972).

Under baseline conditions, rates of responding under the FCN and FCN-S^D schedules are typically equivalent (Laties, 1972). Due to this equivalence in the initial response rates, rate-dependent effects should be similar; thus, baseline response rates can be ruled out as the cause of any drug-produced differences in rate of responding under the two schedules (Laties, Wood, & Rees, 1981). Therefore, there is less ambiguity in the determination of differential drug effects under the FCN and FCN-S^D schedules compared to other stimulus control procedures that lack the ability to control for rate-dependent effects (Laties, 1975).

Studies have shown that some drugs affect responding maintained under the FCN schedule at lower doses, or to a greater extent, than responding maintained under the FCN-S^D schedule (Evans, Laties, & Weiss, 1975; Laties, 1972; Laties et al., 1981; Picker, Leibold, Endsley, & Poling, 1986a; Rees, Wood, & Laties, 1985; Wagman & Maxey, 1969). These results are consistent with those

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from other studies that have shown that behavior under strong exteroceptive stimulus control is affected less by some drugs than is behavior that is without exteroceptive stimulus control (Laties, 1975; Laties & Weiss, 1966; Thompson & Corr, 1974). Thus, it seems that placing an animal's behavior under strong external stimulus control may increase the resistance of that behavior to the effects of certain drugs (Laties, 1975).

The present experiments were designed to compare the effects of four drugs of abuse on responding maintained under FCN and FCN-S^D schedules. The drugs tested were pentobarbital, diazepam, morphine, and phencyclidine (PCP). These drugs were chosen because of the importance of understanding how drugs of abuse alter stimulus control of behavior. Also, each of these drugs is a member of a different pharmacological class from the others and is a prototype drug of the class to which they belong. Therefore, because they are prototypical drugs, their effects should be representative, to some degree, of the other members in each drug class. However, because each drug does represent a different pharmacological class and because the FCN and FCN-S^D schedules produce different levels of stimulus control (Laties, 1972; Laties et al., 1981; Rees et al., 1985), the schedules might be useful in differentiating among the drugs. For example, under a delayed matching-to-sample schedule, pentobarbital, diazepam, and phencyclidine decreased stimulus control, but morphine had little effect (McMillan, 1981, 1982a). In the present study, we wished to determine whether the different levels of stimulus control under these schedules can interact with the different drugs to produce changes in responding that are distinctive for each drug.

METHOD

Subjects

Four adult male Sprague Dawley rats, obtained from Charles River, served as subjects. They were individually housed in a large colony room. The rats were reduced to, and maintained at, approximately 80% of their free-feeding weights by supplemental feedings and had continuous access to water in the home cage. A cycle of lights on at 7:00 a.m. and lights off at 7:00 p.m. was in effect in the colony room.

Apparatus

Sessions were conducted using a Gerbrands two-lever operant chamber (Model G7322). The left lever was a Gerbrands retractable response lever (Model G6311). The levers were located 8.5 cm above the floor of the chamber on either side of a rectangular opening 2 cm above the floor which contained a receptacle for the delivery of 97-mg food pellets (Noyes Formula A). Both levers could be activated by a force in excess of 0.4 N. A bank of four lights (28-V DC lights with translucent red plastic covers) was mounted above each lever. Two 28-V DC houselights mounted on the back quarter of the top panel served as houselights. The operant chamber was housed in a sound-attenuating cubicle equipped with a fan for ventilation and a speaker that provided white masking noise. Behavioral contingencies were controlled with, and data collected by, a TRS-80® model III microcomputer (Radio Shack) interfaced with a Microcomputer Interface II® (Med Associates, Inc.). The computer and interface were located in a room adjacent to that of the operant chamber.

Procedure

After reduction to 80% of their free-feeding body weights, the rats were trained to press the right lever for reinforcer delivery. These sessions, and all subsequent sessions, began with the rats placed in the operant chamber for a 10-min presession period during which the chamber was darkened and lever presses had no programmed consequences. After the completion of this presession period, the houselights were illuminated and the reinforcement contingencies were placed in effect.

During the initial phase of training, the run lever (left lever) was retracted, and each response on the reinforcement lever (right lever) produced a reinforcer. To advance to each new phase of training, the rats had to meet the criterion of earning 50 reinforcers within a 30-min session for three consecutive sessions. For the second phase of training, the run lever was extended, and a single response on this lever resulted in its retraction; a subsequent response on the reinforcement

lever produced the reinforcer. After reinforcer delivery, the run lever was reinserted into the operant chamber. Once the criterion for advancing to the third phase had been met, the number of consecutive run-lever responses required for each reinforcer delivery was rapidly increased. Each time the required number of consecutive responses on the run lever was emitted, this lever was retracted. When the reinforcer was delivered, the run lever was reinserted into the chamber. If a rat responded on the reinforcement lever prior to completing the response requirement on the run lever, the reinforcer was withheld and the response requirement was reset. Once the terminal requirement of eight consecutive responses on the run lever was reached, the retraction of this lever was eliminated. Thus, there were no external cues that signaled the completion of the run-lever response requirement of eight consecutive responses.

The rats responded under the simple FCN schedule until they consistently earned 50 reinforcers within the 30-min session. For subsequent sessions the data were inspected for increasing or decreasing trends in the number of runs (the number of times the rats switched from the run lever to the reinforcement lever) and in the percentage of reinforced runs. When no systematic trends in these performance measures were found, drug testing was initiated.

Sessions were conducted in the mornings, Sunday through Friday, with control sessions (vehicle injection) conducted on Mondays and Thursdays and test sessions (drug injection) conducted on Tuesdays and Fridays. If the subjects did not earn all 50 reinforcers within the 30-min sessions on Sundays or Wednesdays, the control and drug sessions were discontinued until this criterion had been met. Each session lasted for 30 min or until the rats had earned 50 reinforcers.

Drug and vehicle administrations were by intraperitoneal injection. The volume of the drug and vehicle injections was 1 ml/kg of body weight. After injection, the rats were placed in the operant chamber for the presession period. Each drug dose was administered once to each rat in a semirandom order such that ascending or descending dose orders were avoided. After the completion of a dose–response curve for one drug, a minimum of six sessions intervened prior to the testing of a new drug.

Dose–response determinations were conducted for sodium pentobarbital (Sigma Chemical Co.), diazepam free base (Hoffman La Roche), phencyclidine (PCP) hydrochloride (National Institute on Drug Abuse), and morphine sulfate (Mallinckrodt). Pentobarbital, phencyclidine, and morphine were dissolved in physiological saline, and the doses are expressed as the salt. Diazepam was diluted from a stock solution of 5 mg/ml in a vehicle of 40% propylene glycol, 10% ethanol, and 50% physiological saline. The doses of diazepam are expressed as the free base. The control injections for each drug consisted of the appropriate drug vehicle.

After the determination of the dose–response curves for the drugs, the schedule of reinforcement was changed to a multiple FCN FCN-S^D schedule. To avoid confusion, the multiple-schedule components will be referred to as the multiple FCN and FCN-S^D components, and the simple FCN schedule will be referred to by that name. The schedule parameters for the FCN components of the multiple schedule were the same as those of the simple FCN schedule. The FCN-S^D component of the multiple schedule was initiated by a tone and by the illumination of the bank of lights above the run lever. When the rats completed eight consecutive responses on the run lever during the multiple FCN-S^D component, the lights above this lever were turned off. All other schedule conditions were the same as for the multiple FCN component.

Under the multiple schedule, the session was terminated after 30 min had elapsed or after 50 reinforcers had been earned. Each session began with the multiple FCN component in effect, with the schedule components alternating after five reinforcers had been earned (five reinforced runs) or after 5 min had elapsed. After response stability had been attained, the rats consistently earned 25 reinforcers under each of the multiple-schedule components. The multiple schedule was in effect for 30 sessions prior to the analysis of systematic trends in number of runs and percentage of correct runs. When no increasing or decreasing trends in these measures were evident for 10 consecutive sessions, the drug testing phase was initiated. All condi-

tions for drug testing were the same as for the simple FCN schedule.

The dependent variables were the percentage of reinforced runs, the number of responses emitted in each run (which allowed for the determination of conditional probabilities), and the session response rate. The percentage of reinforced runs was defined as the number of runs in which the rats responded at least eight consecutive times on the run lever, prior to switching to the reinforcement lever, divided by the total number of runs. The session response rate was determined by dividing the total number of responses emitted on the run lever by the session length in seconds for each rat. The number of runs per run length was determined for the control as well as for the test sessions, and these data were transformed to conditional probabilities. The conditional probability measure, which is analogous to the IRT/Op measure described by Anger (1963), determines the conditional probability for switching to the reinforcement lever after emitting a particular run length (Laties, 1972). This measure adjusts for the difference in the number of opportunities among the run lengths. For example, the opportunity to switch to the reinforcement lever after a run length of eight occurs only after eight or more consecutive responses are emitted, whereas the opportunity to switch after a run length of five occurs for runs of five or more consecutive responses. Thus, there are more opportunities to emit short, compared to long, run lengths. The conditional probability measure takes this discrepancy into account by dividing the number of times a run length occurred by the number of opportunities the rats had to emit this run length. The conditional probability measure, therefore, provides a measure of the probability of occurrence of each run length given that a response on the reinforcement lever has not prevented the opportunity for that run length to occur (cf. Anger, 1963).

The run length of 16 was the upper recorded run-length limit. If the rats emitted runs of more than 16 consecutive responses, they were recorded in the same terminal bin as the run length of 16. The baseline percentage of reinforced runs was determined by finding the mean percentage of reinforced runs emitted during the control sessions by each rat under each schedule. Session response rates were calculated by finding the group mean for the session rates emitted under each drug dose and control condition. The conditional probability control data were the means of the control sessions for each rat under each FCN schedule. The conditional probability control data presented for each drug condition were obtained by finding the mean conditional probability of the control sessions for each rat under each FCN schedule that occurred during the determination of each drug's dose–response curve. In calculating conditional probabilities, the denominator is continually being diminished. Conditional probabilities were not calculated when fewer than 10 opportunities to respond on the reinforcement key occurred for a run under the simple FCN schedule or fewer than five opportunities remained under the multiple FCN or multiple FCN-S^D components.

Table 1

Baseline percentage of reinforced runs under the FCN schedules, presented as means with standard deviations in parentheses.

Subject	Simple FCN	Multiple FCN	Multiple FCN-S^D
R217	55.0 (7.1)	45.3 (3.0)	95.3 (2.1)
R218	61.0 (5.6)	74.0 (4.4)	92.8 (2.4)
R219	71.3 (4.6)	72.5 (3.9)	93.3 (1.2)
R221	41.0 (4.8)	81.3 (3.2)	90.3 (3.3)
M	57.1	68.3	92.9

RESULTS

Baseline Performance

Table 1 shows that, under control conditions, the mean percentage of reinforced runs was higher under the multiple FCN components than under the simple FCN schedule; however, the effects varied across individual rats. The percentage of reinforced runs for Rat R217 was lower under the multiple FCN component than under the simple FCN schedule, whereas those for Rats R218 and especially R221 were higher and that of R219 was about the same. In contrast, the percentage of reinforced runs under the multiple FCN-S^D component was higher than that under both the simple FCN schedule and the multiple FCN component for all rats.

Figure 1 shows the conditional probability

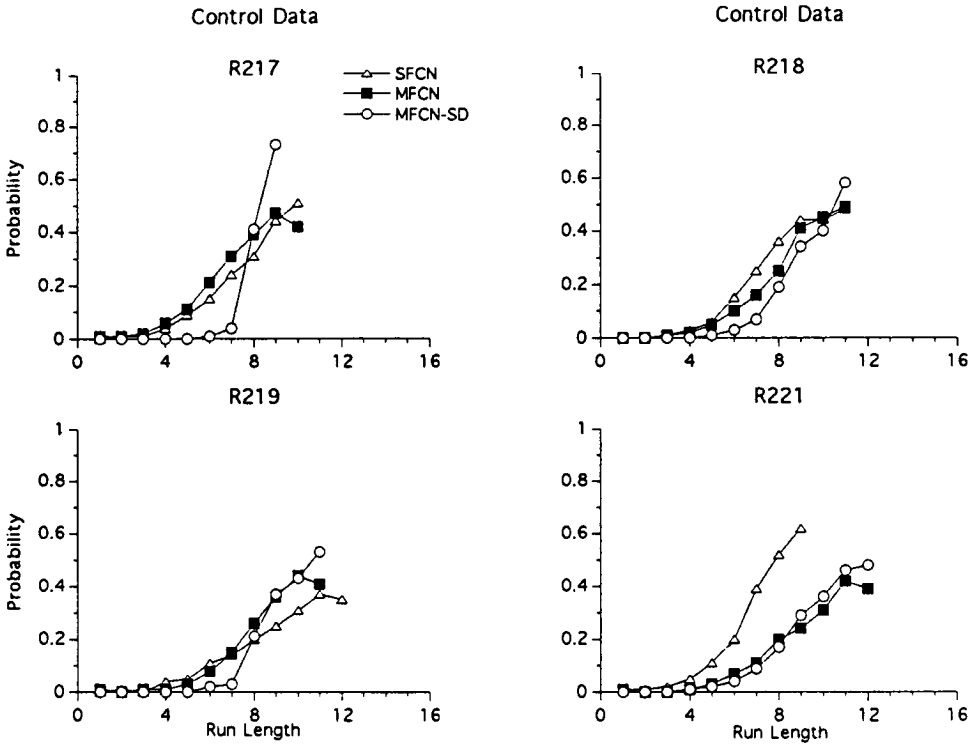

Fig. 1. The mean conditional probability control data for the simple FCN schedule (open triangle), the multiple FCN component (closed square), and the multiple FCN-S^D component (open circle), for each of the 4 rats. These data are the means of the control sessions for each rat obtained under each FCN schedule.

of switching from the run lever to the reinforcement lever as a function of run length under all schedules for each rat. For all rats, under all schedules, the conditional probability of a switch to the reinforcement lever generally increased as the length of the run increased. For Rats R217, R218, and R219, the conditional probability of terminating a run short of the minimum required for reinforcement (eight consecutive responses) under the FCN-S^D component of the multiple schedule was less than that obtained under the other schedules, while for Rat R221 the conditional probability curves were similar under both components of the multiple schedule. For Rat R221 and to a lesser extent for Rat R218, the conditional probability curves for the simple FCN schedule were to the left of the curves of the multiple-schedule components, suggesting an increased probability of a switch to the reinforcement key after shorter runs under the simple FCN schedule. For Rats R217 and R219 the conditional probability curves for the simple FCN schedule were slightly to the right of those emitted under the FCN component of the multiple schedule at the longer run lenths.

Dose–Response Curves for Percentage of Reinforcement

Dose–response curves are shown for individual rats and for the group mean for all drugs under all schedules in Figure 2. Only decreases in the percentage of reinforced runs were obtained for the group means, although occasionally individual animals showed small increases in the percentage of reinforced runs.

Responding under the simple FCN schedule was affected at the lowest doses of diazepam, with 1 rat no longer responding after receiving 1.0 mg/kg diazepam and the other 2 rats showing a decrease in the percentage of reinforced runs. Under the FCN and FCN-S^D components of the multiple schedule, responding was well maintained after receiving 1.0 mg/kg diazepam in all rats and the per-

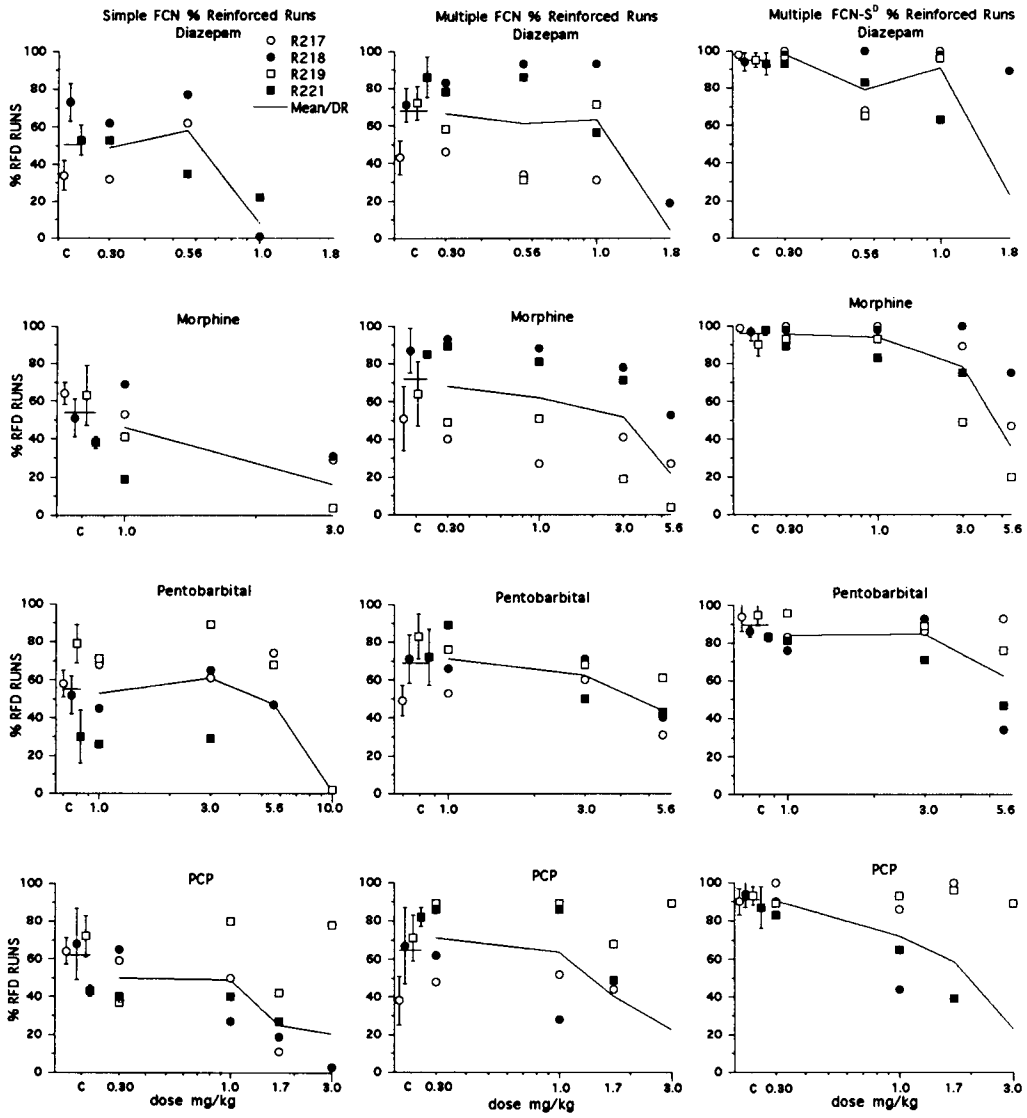

Fig. 2. The percentage of reinforced runs (% RFD RUNS) for the simple FCN schedule (left column), the multiple FCN component (middle column), and the multiple FCN-S^D component (right column). The effects of the four drugs are shown with the order of presentation being diazepam (top row), morphine (second row), pentobarbital (third row), and PCP (bottom row). Each subject is represented by a unique symbol: open circle for R217, filled circle for R218, open square for R219, and filled square for R221. The mean dose–response values are represented by the solid lines. To be consistent, the data of each of the 4 rats are included in the mean values even when a rat did not emit any reinforced runs (i.e., 0% reinforced runs). The absence of a rat's symbol indicates that the rat failed to emit a reinforced run at that dose. The control values are shown on the left side of each graph, with the vertical lines representing ±1 *SD* and the horizontal line showing the group mean. Because of a lack of behavioral stability, diazepam was not administered to Rat R219 under the simple FCN schedule.

centage of reinforced runs was only slightly affected. At 1.7 mg/kg diazepam, responding was eliminated under both multiple-schedule components in 3 of the 4 rats.

The effects of morphine were qualitatively similar to those of diazepam. The 3.0 mg/kg dose of morphine had greater effects on responding maintained under the simple FCN schedule than under either component of the multiple schedule. The 5.6 mg/kg dose of morphine also produced a greater effect under the simple FCN schedule in that re-

sponding in all rats was eliminated, whereas under the multiple-schedule components the responding of only 1 rat was eliminated at this dose.

Unlike the differential effects of diazepam and morphine, the effects of pentobarbital on responding were similar across all three schedule conditions. Rat R221, however, did fail to respond after the 5.6 mg/kg dose under the simple FCN schedule. For PCP, the effects on responding of the 1.7 mg/kg dose were only slightly greater under the simple FCN schedule than under either component of the multiple schedule. Although the 3.0 mg/kg dose of PCP suppressed the responding of the other rats under each of the FCN schedules, the responding of Rat R219 was not affected by PCP.

Effects of Drugs on Conditional Probability Distributions

The effects of the drugs on the conditional probability distributions are shown in Figures 3 through 6. In these figures, loss of stimulus control is shown by a shift of the conditional probability curve to the left or by an increase in the conditional probability of some, or all, of Bins 1 through 7. Such effects would be expected to lower reinforcement rates. Loss of stimulus control might also be shown by a decrease in the conditional probability of run lengths of more than seven consecutive responses, although this effect would not necessarily lower reinforcement rate. These two effects might be combined, and examination of Figures 3 through 6 shows that both effects were sometimes observed in the same rat at the same dose. It is also possible that a drug might improve stimulus control under an FCN schedule. This is shown by a decrease in the conditional probabilities of runs of seven or fewer consecutive responses or an increase in the conditional probability of runs of more than seven consecutive responses. These effects would generally increase the percentage of reinforced responses. Such effects were rare.

Diazepam. Because the responding of Rat R219 was not stable when the simple FCN schedule dose–response curve for diazepam was determined, the data for this rat were not included in the dose–response determination. At doses that did not eliminate responding, the effects of diazepam on conditional probabilities under the simple FCN schedule were not striking (Figure 3). For Rat R217, the administration of the 0.56 mg/kg dose produced a decrease in the probability of ending a run too soon and an increased probability of switching after 10 consecutive responses on the run lever. The conditional probabilities of Rat R218 were little affected at doses of diazepam that did not eliminate its responding under the simple FCN schedule. Rat R221 showed somewhat increased conditional probabilities of run lengths of eight or less at doses of 0.56 mg/kg and 1.0 mg/kg diazepam and a decreased probability of run lengths of 10 responses after the 0.3 and 0.56 mg/kg doses under the simple FCN schedule. The minimal effect of diazepam on the conditional probabilities emitted by these rats is largely due to the suppression of responding at the higher doses of this drug.

Under the FCN component of the multiple schedule, one or more doses of diazepam produced increases in the conditional probability of short runs (seven or fewer consecutive responses) for all rats except R221. The conditional probability of long runs (eight or more consecutive responses) was decreased in all rats, although the effects on the responding of Rat R217 were minimal compared to the effects in the other rats. Except for increases in the probability of run lengths of four to eight responses after the 0.56 mg/kg dose of diazepam, the conditional probabilities of Rat R217 were little affected by diazepam under the multiple FCN-S^D component until responding was eliminated at the dose of 1.8 mg/kg. For Rats R218 and R219, the doses of 0.56 (Rat R218 only) and 1.0 mg/kg diazepam produced a shift to the right in the conditional probability function such that, for these rats, only long run lengths were emitted at this dose. For Rat R221 the 1.0 mg/kg dose increased the conditional probability of short runs and the 0.56 mg/kg dose decreased the probability of longer runs.

Morphine. Morphine, at the doses that produced an effect, typically caused an increase in the probability of short run lengths (Figure 4). Although this was the usual effect of morphine, for Rat R217 under the multiple FCN component and for Rat R218 under the simple FCN schedule, the conditional prob-

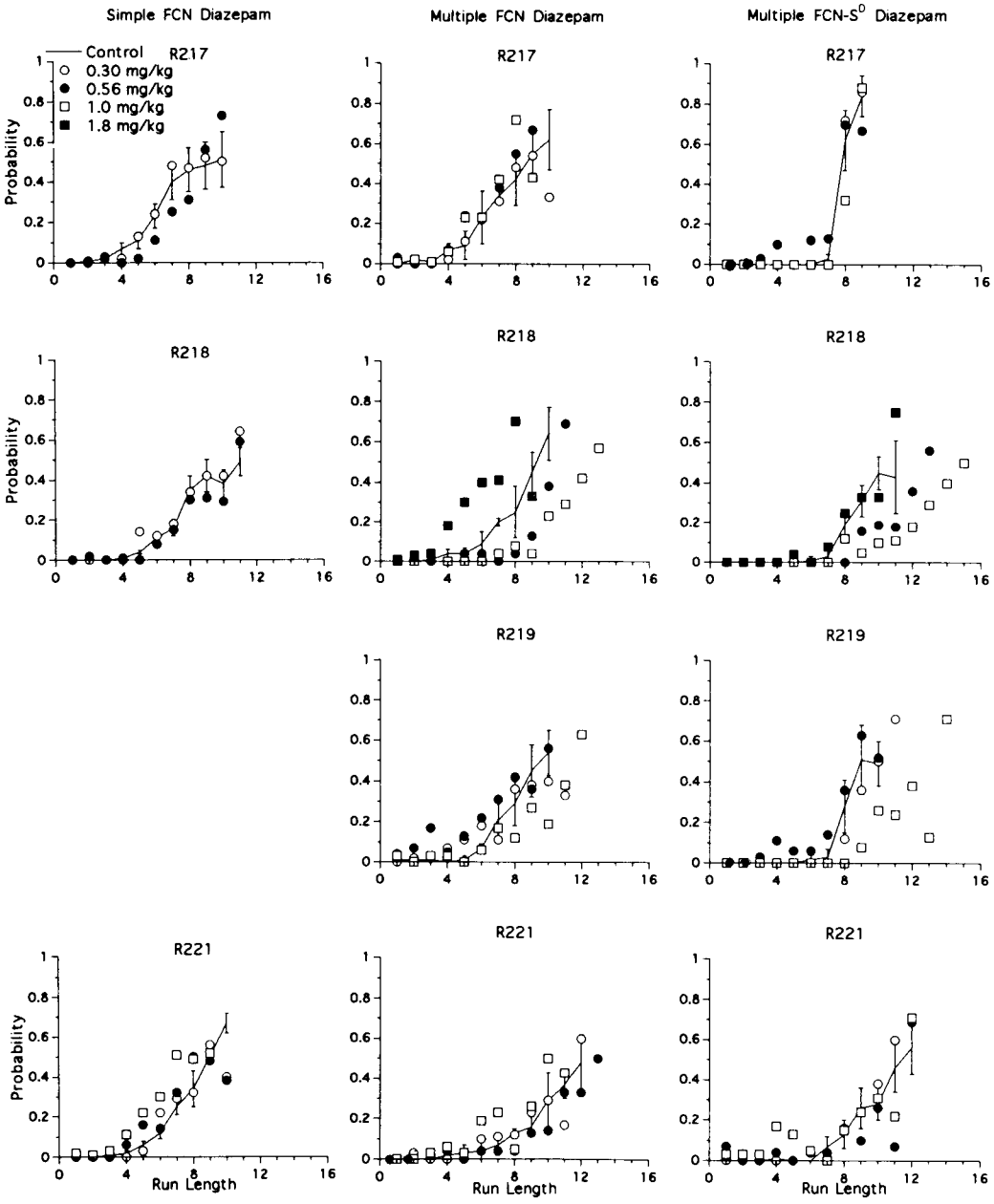

Fig. 3. The effect of diazepam on the conditional probability of switching from responding on the run lever to the reinforcement lever. The simple FCN schedule is represented in the left column, and the multiple FCN component and the multiple FCN-S^D component are represented by the middle and right columns, respectively. Each row presents the data for 1 rat, with the order being R217, R218, R219, and R221 from the top to the bottom row. The mean conditional probability control data are represented by the solid line, and the vertical lines show ±1 *SD*. The ordinate represents the conditional probability, and the abscissa represents the run length. Diazepam was not administered to Rat R219 under the simple FCN schedule because its behavior was not stable at that time.

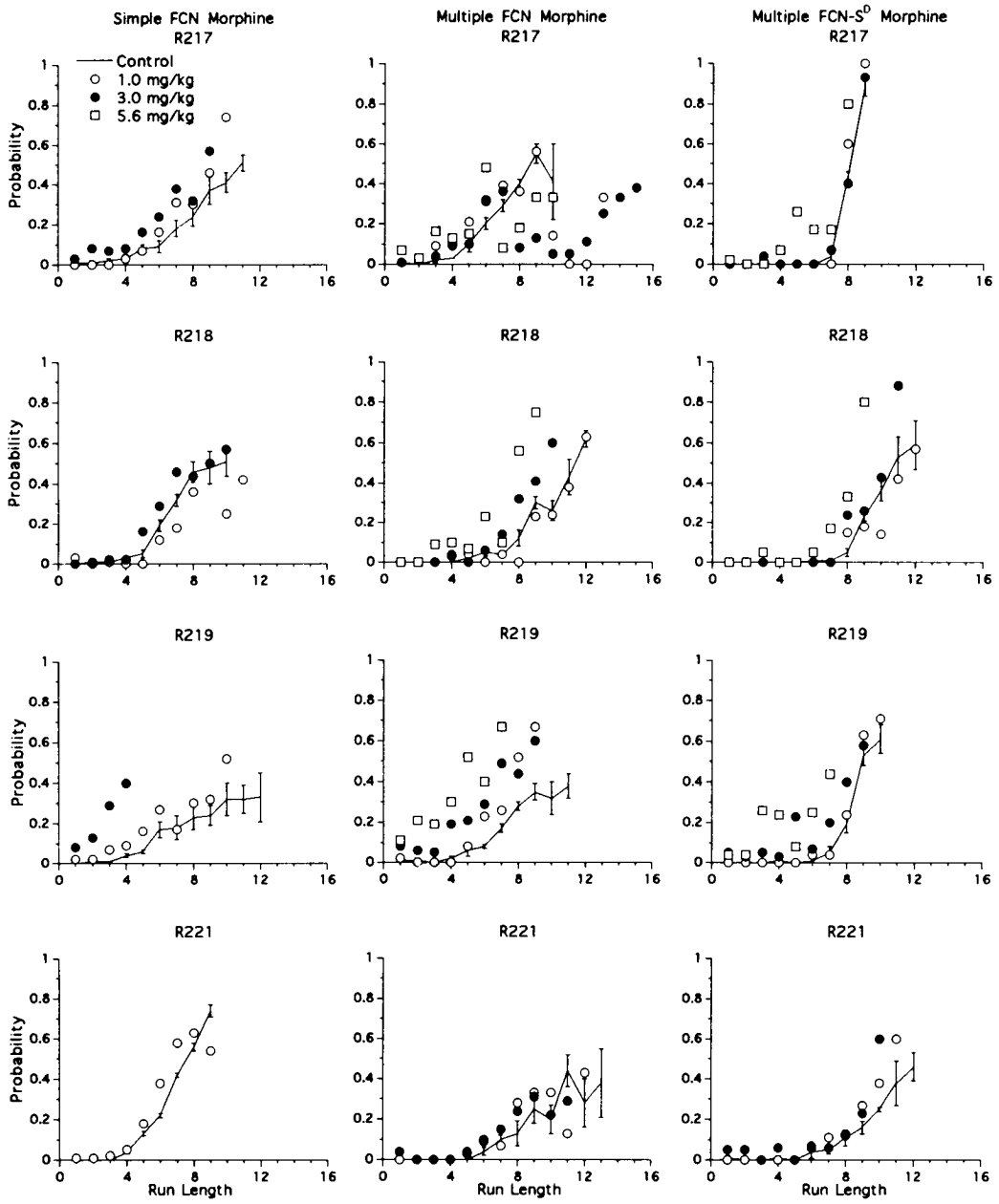

Fig. 4. The effect of morphine on the conditional probability of switching from responding on the run lever to the reinforcement lever. Details are as in Figure 3.

abilities of long run lengths were decreased at some doses.

The typical effect of morphine to increase the conditional probability of short run lengths occurred under each FCN schedule, although this effect was somewhat less frequent under the simple FCN schedule due to the suppression of responding of Rats R219 and R221 at higher doses and the suppression of responding of all the rats at the dose of 5.6 mg/kg. Under the FCN component of the multiple schedule, the increased probability of short runs can be observed as a shift to the left in the conditional probabilities for

Rats R218 and R219, with this shift usually occurring over two or more dose levels. A similar shift to the left in the conditional probabilities for Rats R217, R218, and R219 can be observed under the multiple FCN-S^D component, with the most consistent effect occurring at the 5.6 mg/kg dose. Although, for the most part, morphine did not alter the conditional probability distributions produced by Rat R221, the responding of this rat was eliminated by doses of morphine that altered, but did not eliminate, the responding of the other rats.

Pentobarbital. The effects of pentobarbital, as shown in Figure 5, were more like those of diazepam than those of morphine. There were few effects of pentobarbital under the simple FCN schedule at doses that did not severely suppress responding; however, when effects occurred the conditional probabilities at run lengths of eight or more responses were usually decreased in Rats R217 and R218, and Rat R219 showed some increases in the conditional probability of run lengths of eight or more responses, especially after the 1.0 mg/kg dose. Under the multiple-schedule components, there was an increase in the conditional probability of short runs and a decrease in the conditional probability of long runs for Rats R218 and R219 and an increase in the length of the longest run emitted at the doses of 3.0 and 5.6 mg/kg. For R221, there was an increase in the conditional probability of long run lengths at the 5.6 mg/kg dose of pentobarbital, although the longest run emitted at this dose was shorter than the longest run emitted under the control conditions. Few consistent effects occurred for Rat R217. Pentobarbital produced few effects on responding under the FCN-S^D component of the multiple schedule, except for some increases in the conditional probability of responses in the early bins after receiving the 5.6 mg/kg dose. Under the FCN component of the multiple schedule, the 5.6 mg/kg dose slightly increased the conditional probability of responding in the early bins for all rats except R217. The 3.0 mg/kg dose (Rats R217 and R218) and the 5.6 mg/kg dose (Rats R218 and R219) decreased the conditional probability of responding at or near the bin associated with the minimum number of responses on the run lever required to produce the reinforcer (Bin 8).

PCP. PCP produced increases in the conditional probability of switching to the reinforcement lever after runs of fewer than eight responses under the simple FCN schedule in each rat after the 1.7 mg/kg dose (Figure 6). This effect was especially pronounced for Rats R217 and R218. For Rat R221, the small increase in the conditional probabilities of short run lengths observed after the 1.7 mg/kg dose of PCP may have been due, at least partly, to the dominance of short run lengths in the conditional probability baseline. Only Rat R219 showed a reliable decrease in the conditional probability of runs of eight or more responses after PCP administration under the simple FCN schedule. In contrast, under the FCN component of the multiple schedule, decreases in the conditional probability of run lengths of eight or more responses were observed after one or more doses of PCP in all rats. Increases in the conditional probability of runs of fewer than eight responses were also observed in most rats, but the effects were generally smaller under the FCN component of the multiple schedule than under the simple FCN schedule. Under the FCN-S^D component of the multiple schedule the responding of Rat R217 was little affected, whereas PCP produced only increases in the probability of shorter runs by Rat R221. The responding of Rat R218 showed both increases in the conditional probability of short runs and decreases in the conditional probability of long runs. Rat R219 showed both increases and decreases in the conditional probability of long runs.

Effects of Drugs on Rate of Responding on the Run Lever

Table 2 shows the mean session response rates under the control conditions and after drug administration for each schedule. This table shows that, under the control conditions, there were no significant differences in session response rates within the three schedules. It appears that the session response rates under the morphine control conditions might have been higher than those of the other drugs, particularly for the multiple FCN component. However, because the standard errors overlap, it is unlikely that there is a true difference in response rates among these control conditions. The data in Table 2 also show that doses of the drugs were ad-

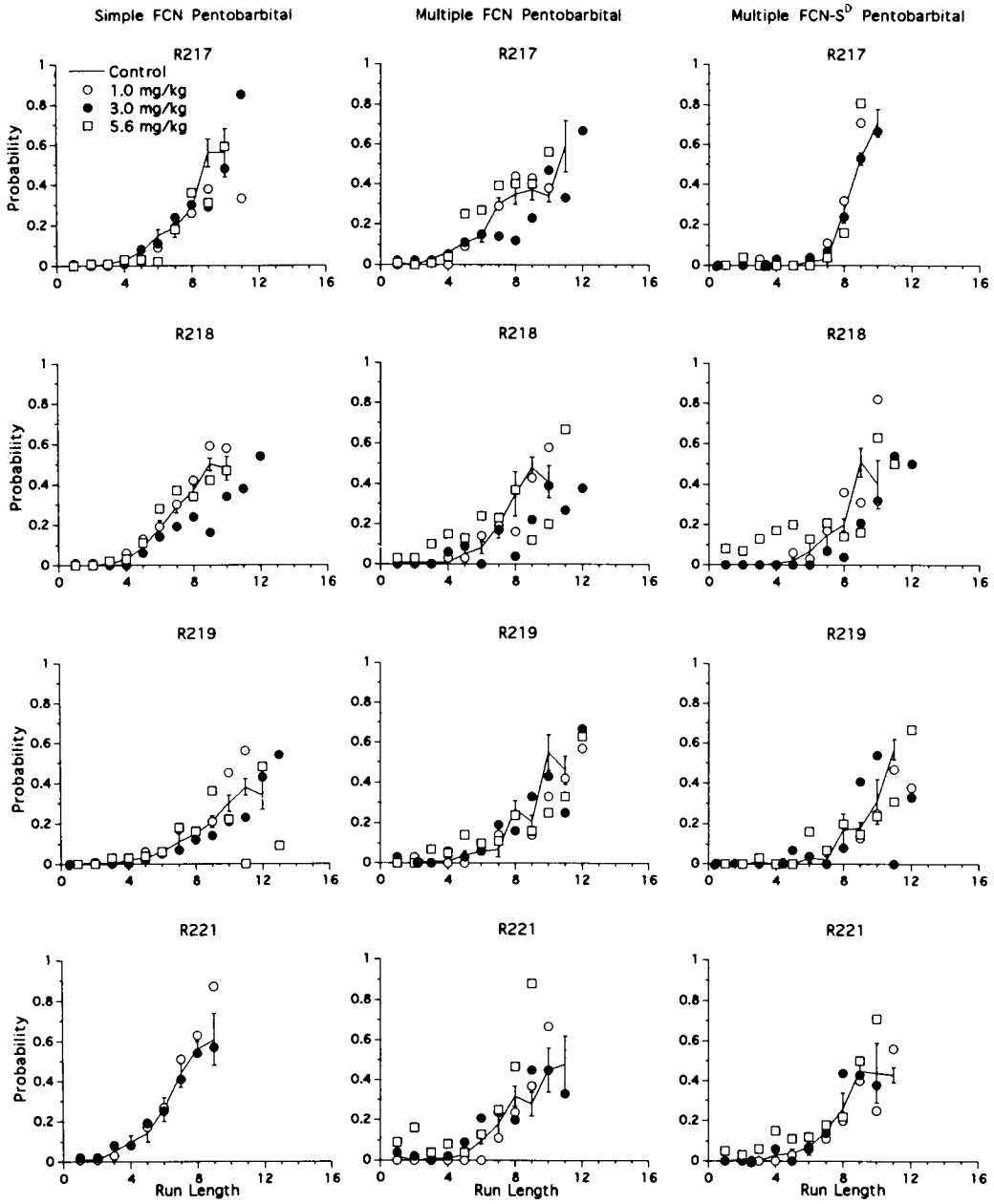

Fig. 5. The effect of pentobarbital on the conditional probability of switching from responding on the run lever to the reinforcement lever. Details are as in Figure 3.

ministered up to levels that markedly suppressed response rates. The greater sensitivity of responding under the simple FCN schedule to the effects of diazepam and morphine, relative to the effect of these drugs on responding under the FCN components of the multiple schedule, can also be seen in this session response-rate measure.

DISCUSSION

All of the drugs in this study produced a loss of stimulus control over responding under each of the FCN schedules, resulting in a decrease in the percentage of reinforced responses as the drug dose increased. Based on an analysis of the conditional probabili-

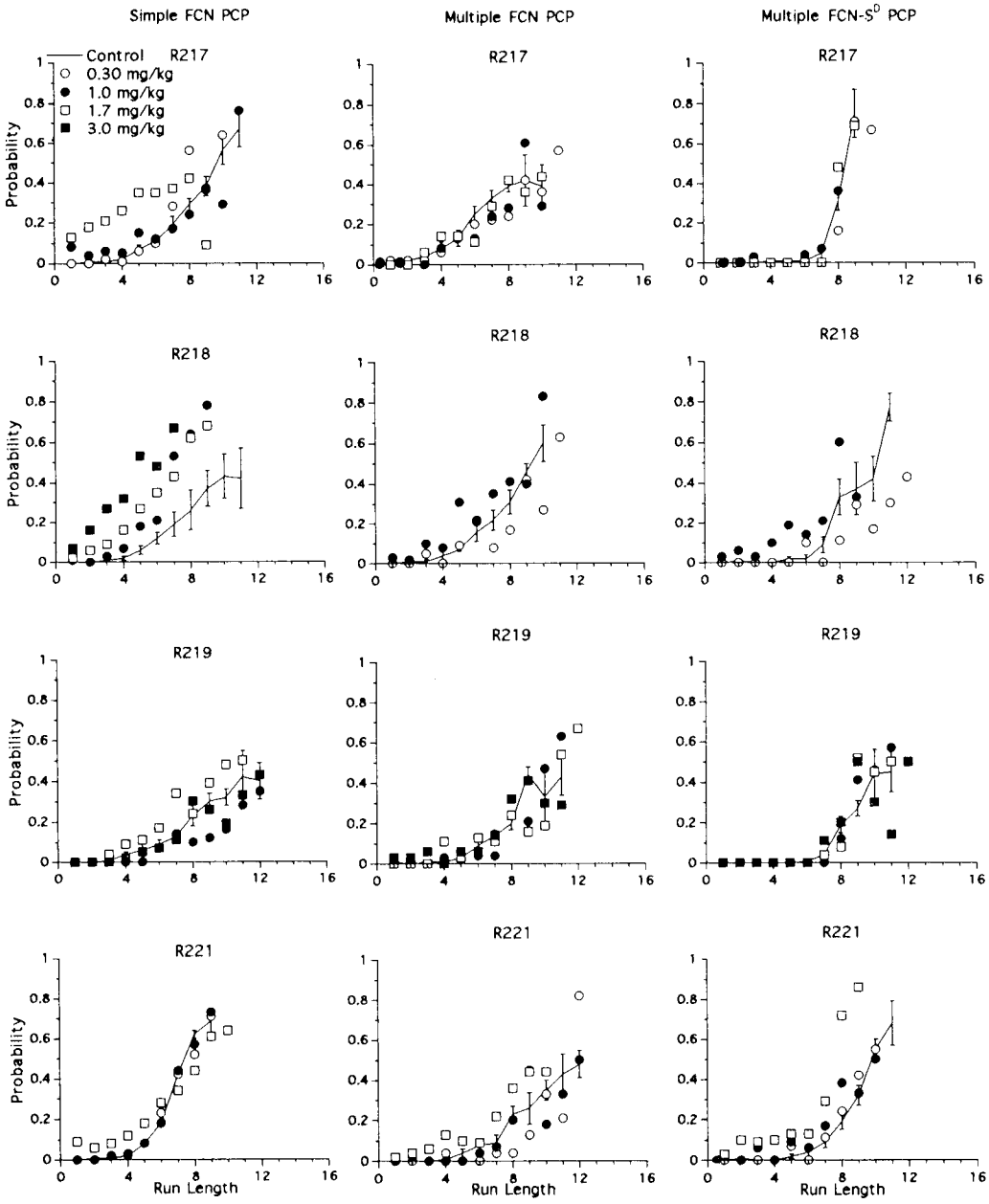

Fig. 6. The effect of PCP on the conditional probability of switching from responding on the run lever to the reinforcement lever. Details are as in Figure 3.

ties, it seems that there were two ways in which these drugs decreased stimulus control of responding. Rats either switched to the reinforcement lever after a run of fewer than eight responses (which resulted in the resetting of the response requirement without reinforcer delivery), or the rats continued to respond on the run lever after eight consecutive responses had been emitted (resulting in more responses on the run lever than necessary and a longer latency to reinforcement).

Diazepam and pentobarbital appeared to have similar effects on responding across

Table 2

FCN schedule mean response rates (responses per second).

Drug and dose	Simple FCN	Multiple FCN	Multiple FCN-S^D
Diazepam			
Control *M*	0.66 (0.06) *SE*	0.64 (0.06)	0.57 (0.09)
0.30	0.64 (0.07) *SD*	0.76 (0.06)	0.65 (0.13)
0.56	0.56 (0.27)	0.61 (0.11)	0.58 (0.21)
1.00	0.28 (0.33)	0.61 (0.19)	0.62 (0.19)
1.70	0.00	0.16 (0.33)	0.15 (0.29)
Morphine			
Control *M*	0.69 (0.09)	0.78 (0.09)	0.70 (0.10)
1.0	0.62 (0.14)	0.65 (0.03)	0.58 (0.10)
3.0	0.27 (0.31)	0.57 (0.21)	0.50 (0.13)
5.6	0.00	0.23 (0.15)	0.26 (0.20)
10.0		0.00	0.00
Pentobarbital			
Control *M*	0.61 (0.03)	0.62 (0.06)	0.61 (0.05)
1.0	0.56 (0.06)	0.76 (0.11)	0.71 (0.10)
3.0	0.73 (0.04)	0.72 (0.16)	0.67 (0.13)
5.6	0.45 (0.29)	0.65 (0.27)	0.60 (0.10)
10.0	0.02 (0.04)	0.00	0.00
PCP			
Control *M*	0.64 (0.05)	0.62 (0.07)	0.58 (0.08)
0.30	0.66 (0.12)	0.58 (0.10)	0.58 (0.08)
1.00	0.76 (0.16)	0.63 (0.08)	0.58 (0.12)
1.70	0.59 (0.17)	0.50 (0.17)	0.44 (0.15)
3.00	0.30 (0.35)	0.15 (0.15)	0.13 (0.13)

these FCN schedules. For example, both diazepam and pentobarbital decreased the conditional probability of long runs under both components of the multiple schedule at some doses and, at other doses, these drugs increased the conditional probability of short runs that were emitted by 3 of the 4 rats under both components of the multiple schedule. For Rat R217, neither diazepam nor pentobarbital caused an increase in the conditional probability of long run lengths, although it did seem that the conditional probabilities of short runs emitted by this rat were increased at some doses. Under the simple FCN schedule these effects on the responding of the rats were less impressive. It may be that the drug effects on responding under the simple FCN schedule were less pronounced because at the doses at which the most marked effects on conditional probability occurred under the multiple schedule, the responding of the rats under the simple FCN schedule was depressed or eliminated. Nevertheless, even under the simple FCN schedule, pentobarbital effects on responding can be seen for Rats R218 and R219.

The similarity of diazepam and pentobarbital effects on responding maintained by these FCN schedules is consistent with the similar effects of barbiturates and benzodiazepines on behavior maintained by many other reinforcement schedules. To mention a few examples, drugs from both classes increase the frequency of punished responding (McMillan, 1975), disrupt responding under matching to sample (McMillan, 1981), disrupt repeated acquisition of response sequences (Thompson, 1978), and produce similar discriminative stimuli (Shannon & Herling, 1983).

PCP has also been reported to have many effects that resemble those of pentobarbital and diazepam. Like these two drugs, PCP produces an increase in the frequency of punished responding, although the effects are rather small (Wenger, 1980). PCP also disrupts responding under matching to sample (McMillan, 1981) and repeated acquisition (Thompson & Moerschbaecher, 1979); however, there appears to be only partial stimulus substitution between PCP and the barbiturates (McMillan & Wenger, 1983). Under the simple FCN schedule, PCP seemed to produce higher conditional probabilities after short runs than did diazepam or pentobarbital, although this might be due, at least in part, to the suppression of responding after the higher doses of these latter two drugs. Under the components of the multiple schedule, there were less obvious differences in the effects of PCP, diazepam, and pentobarbital on the conditional probabilities emitted by the rats. Thus, PCP produced effects on responding under the FCN schedules that resembled those of diazepam and pentobarbital.

Morphine produced effects on responding under these FCN schedules that were different from the effects of the other drugs. Under the multiple-schedule components, morphine rarely decreased the conditional probability of switching to the reinforcement lever after runs of eight or more responses, as did diazepam, pentobarbital, and PCP, although the conditional probability distributions for Rat R217 under the FCN component of the multiple schedule provide clear exceptions to this statement. Unlike the other

drugs, morphine has few effects on matching-to-sample responding (McMillan, 1981), it usually produces little effect on punished responding (McMillan, 1975), and the morphine discriminative stimulus does not substitute for the pentobarbital (Herling, Valentino, & Winger, 1980) or for the PCP stimulus (McMillan, 1982b).

Despite the differences suggested between morphine and the other drugs, responding under the FCN schedules was not very useful in differentiating among the drugs. Each of the drugs disrupted stimulus control, and they all decreased the rate of reinforcement under each of the FCN schedules. Because there were few consistent differences in the effects of the drugs on the conditional probability of switching from the run lever to the reinforcement lever, this measure of stimulus control did not provide a useful procedure for distinguishing among the drugs.

The results of a number of studies suggest that behavior controlled by FCN-S^D schedules is more difficult to disrupt with drugs than is behavior controlled by FCN schedules. For example, scopolamine and *d*-amphetamine (Laties, 1972), clonazepam (Picker et al., 1986a), pimozide (Szostak & Tombaugh, 1981), and valoproic acid, phenytoin, phenobarbital, and diazepam (Picker, Leibold, Endsley, & Poling, 1986b) have been shown to have greater effects on responding under an FCN schedule than on responding emitted under an FCN-S^D schedule. Prior to the present experiments, Schlinger, Wilkenfield, and Poling (1988) and Laties (1972) presented evidence that this differential sensitivity does not always occur. Schlinger et al. (1988) attributed the lack of a differential drug effect to the context of the mixed schedule that they employed.

We also failed to find many differences in the effects of the drugs on responding maintained under FCN and FCN-S^D components within the context of a multiple schedule. A possible explanation is that under a multiple FCN FCN-S^D schedule, the control of responding by each of the component schedules is influenced by the other schedule. Under the FCN-S^D component, stimulus control would be demonstrated by a switch in responding from the run lever to the reinforcement lever as soon as the discriminative stimulus signals that the reinforcer is available. Thus, the absence of the exteroceptive discriminative stimulus could serve as a signal for continued responding on the run lever. This may explain why some rats showed an increase in the conditional probability of run lengths greater than eight when responding under the multiple FCN component. Under the FCN-S^D component, however, the occurrence of the discriminative stimulus should serve as a cue for switching from the run lever to the reinforcement lever. Some rats, though, continued to respond on the run lever after the discriminative stimulus was presented. Perhaps the reinforcement of long run lengths under the multiple FCN component weakened the control exerted by the discriminative stimulus as regards the end point of the runs under the multiple FCN-S^D component.

It might be argued that the failure to find differences in drugs under the components of the multiple schedule resulted from poor control by the visual stimulus under the FCN-S^D component of the multiple schedule. It is possible that the red lights that served as the discriminative stimulus were not discriminable because rats are not sensitive to long wavelengths of light. The results displayed in Table 1, however, suggest that the stimulus exerted considerable control over responding, in that the percentage of reinforced runs under the multiple FCN-S^D component was greater for each rat compared to the percentage of reinforced runs under the multiple FCN component.

Laties et al. (1981) studied the effects of *d*-amphetamine on responding under FCN and FCN-S^D schedules in two groups of rats. One group responded under simple schedules and the other responded under a multiple schedule. Although they found that *d*-amphetamine increased the conditional probability of short runs under the FCN schedule at doses that did not affect responding under the FCN-S^D schedule, they also found context affects. A dose of 3.0 mg/kg *d*-amphetamine, the highest dose tested, did not affect the conditional probabilities emitted under the simple FCN-S^D schedule, but when this schedule was a component of a multiple schedule, 1.0 mg/kg and higher doses of *d*-amphetamine increased the conditional probability of short run lengths. The control level for percentage of reinforced runs was also found to depend on the schedule context. The control percentages for the simple FCN-S^D schedule and for the

multiple FCN-S^D component were comparable, but the percentage of reinforced runs obtained under the multiple FCN component was approximately 20% greater than the percentage obtained under the simple FCN schedule. Thus, as in the present study, Laties et al. (1981) found that whether the context of the FCN schedule was that of a simple schedule or a multiple schedule determined the percentage of reinforced runs obtained by the rats.

Another interesting finding was that diazepam and morphine suppressed responding more under the simple FCN schedule than when the FCN was a component of the multiple schedule. There are several possible explanations for this finding. First, it is possible that the context of the FCN schedule may have influenced the effects of the drugs. For example, the higher percentage of reinforced runs under the control conditions of the multiple FCN component may have acted to sustain responding beyond what could be sustained under the simple FCN schedule.

Second, the simple FCN schedule was studied first; thus, it is possible that some tolerance to the effects of these drugs may have developed by the time the second dose–response determinations were conducted. Third, because the simple FCN schedule was studied first, the rats had a longer exposure to the FCN reinforcement contingencies by the time that the effects of the drugs on responding were determined for the multiple-schedule components. This increased training under the schedule contingencies might have made the behavior more resistant to drug effects. It is unfortunate that we did not try to replicate drug effects under the simple FCN schedule upon completion of these experiments. Instead, we elected to study the effects of a large number of additional drugs (not reported here), during which subject attrition eliminated the possibility of the replication of the drug effects under the simple FCN schedule.

In summary, all four drugs decreased stimulus control under the FCN schedules and produced a decrease in the percentage of reinforced runs. Diazepam, pentobarbital, and PCP increased the conditional probability of responding on the reinforcement lever after short runs (fewer than eight consecutive responses) at some doses, whereas other doses produced a shift to the right of the conditional probability distribution resulting in runs of longer lengths than were emitted under control conditions. Morphine more consistently produced increases in the conditional probability of short run lengths without producing a shift to the right in the distribution of conditional probabilities. There were few differences in the effects of drugs on responding under the multiple FCN component and the multiple FCN-S^D component. Responding under the simple FCN schedule was affected at lower doses than was responding under the FCN component of the multiple schedule, but it was not possible to determine if this was an effect of the schedule context or the order in which the experiments were conducted.

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